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THE EFFECT OF AMBIENT TEMPERATURE ON HUMAN STRENGTH

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ABSTRACT

Impact of environmental conditions like temperature is usually not considered in the measurement of work content analysis. However, to ensure healthy work conditions, it is imperative that studies on the effects of heat and cold stress on workers' capacity are carried out and existing guidelines on working capacity be suitably modified. In this study, the effect of heat stress on the physical strength of subjects measured in terms of average push/ pull/ pedal/ grip force applied over 30 seconds was recorded. In dry bulb temperature studies, it was found that subjects showed a maximum strength at 20°C or 25°C and a 30% and 35 % drop in strength was observed at 5°C and 40°C respectively. In case of wet bulb globe temperature (WBGT), the maximum strength was recorded between 13°C to 21°C and a 31% and 41% drop in strength was observed in the range 3°C to 5°C and 37°C to 39°C respectively. Statistical analysis of strength at ambient temperatures between 5°C to 40°C dry bulb values gave a second order "inverted-U" relationship between strength and temperature and, a second order "U-shaped" relationship between the drop in strength and temperature

***KEYWORDS**: Physical Strength, Push, Pull, Pedal, Grip, Heat Stress & Cold Stress*

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Original Article

INTRODUCTION

Global warming aggravated due to increased greenhouse gas emissions represents a threat to human life. Lethal heat waves due to ongoing climate change are also predicted to occur more frequently[1]. Working in these extreme temperatures will require a complete overhaul of the current globally adopted systems of work measurement, work severity, and postural analysis. At present, most standard work measurement techniques do not account for the impact of environmental variables like temperature on the work content analysis and the number of persons required for the given quantum of work. In industries as well as in the unorganized sector, variations in thermal conditions due to seasonal changes are not considered while determining standard output level for the labor and for assessment of human resource requirement. It is therefore imperative that studies on the impact of heat and cold stress on working capacity be carried out and existing guidelines be modified. Kjellström[2] has suggested that climate change is expected to become severe and each country is recommended to develop a local occupational health impact analysis and prevention plan to protect workers' health.

Environmental conditions in which work is performed are usually considered out of the scope of most research work, although their general impact is well known. In industries as well as in the unorganized sector, variations in thermal conditions due to seasonal changes are not considered while determining standard output level for the labor and for assessment of human resource requirement.

There is only a very small amount of literature reviewing the effects of cold temperatures on physical strength. A gradual loss of manual dexterity is experienced with the decline in the temperature of various physiological structures including skin, muscle, receptor, nerve, and joint temperatures. De Jong *et al*.[3] observed that there is a reduction in nerve conduction velocity that drops strongly at a nerve temperature below 20°C and is effectively blocked at 10°C. Strength and sustainability are also affected by declining temperatures. In the cold series of experiments conducted by Meese *et al.*[4] finger strength and speed and manual dexterity on an assembly line taskwere found to be decreased as the temperature fell from 24°C through 18°C, 12°C to 6°C.

The effects of thermal environments on the risks associated with manual handling were also studied in a research report by S Powell[5] for the Health and Safety laboratory. Studies were done at two thermal environments namely, cold environment 0^{o}C to 10^{o}C and hot environment 29^{o}C to 39^{o}C. The authors recommended that decreasing lifting frequency in hot environments would help in reducing the extra physiological strain imposed by hot thermal environments.

Furtado *et al.*[6] studied the effect of heat stress on physiological effects and task performance and found that simple tasks were less effected by heat stress compared to complex tasks such as tracking, monitoring, and multiple tasks. Kamon & Belding[7] assessed the physiological cost of carrying loads in temperate and hot environments. The authors observed an increased heart rate at elevated temperatures due to heat stress. Snook & Ciriello[8,9] investigated the effects of heat stress on lifting, pushing and carrying tasks using a sample of sixteen male industrial workers. Two environments were studied, moderate (17.2°C WBGT) and hot (27°C WBGT). It was found that in the hot environment, the self selected workload was significantly reduced by 20% for the lifting task and that heart rate was significantly increased by 9 - 10 beats.min^{-1}. A similar methodology was used by Hafez & Ayoub[10] for testing six male subjects who performed a lifting test similar to that described by Snook & Ciriello. At a frequency of 3 lifts.min^{-1} there was an 18.3% reduction in weight lifted between 27° C and 32°C. At 6lifts.min^{-1} there was a 21.5% decrease in weight lifted. The authors suggested that individuals working in hotter environments (specifically 32°C WBGT) should reduce the weight of the load lifted and take longer rest periods.

S.A.Yildizel, *et al.*[11] assessed the impact of heat stress on performance and worker health at a construction site in Moscow. Temperatures were varied between 16 to 23 degrees centigrade in two sets of experiments involving more than 193 workers. No specific quantification of the impact of temperature on work severity, in general, was established. Matt Brearley *et al.*[12] undertook a study of electrical utility workers in the northern territory of Australia to examine their physiological and fluid balance responses to climatic conditions. Authors recommended more studies to extend the impact on broader occupational settings.

Jeremiah Chinnadurai *et al.*[13] undertook a study of construction workers in Chennai, India to estimate the productivity in construction work under the influence of heat stress using the Predictive Mean Vote (PMI) index. Their study showed that working outdoors had a significant adverse impact on productivity to the extent of 35%.

Galloway and Maughan[14] demonstrated an 'inverted-U' relationship between ambient temperature and submaximal exercise tolerance time, with a peak at 10.5°C and equivalent decreases at 3.6°C and 20.6°C, with a further impairment at 30.5°C. Ramsey *et al.*[15] found that temperatures below and above those typically preferred by most people had a significantly detrimental effect on the safety-related behavior of workers. Similarly, Tawatsupa B[16] observed a strong association between heat stress and occupational injury. Dunne *et al.*[17] found a reduction in labor capacity due to heat stress.

Stephen S Cheung *et al.*[18], have reviewed the effect of thermal stress, human performance and physical employment standards. The review surveys the major occupational impact of thermal extremes and existing employment standards, proposing guidelines for improvement and areas for future research.

Priya Dutta, *et al.*[19] assessed the impact of heat on the health of construction workers in Ahmedabad, Gujarat. The assessment was a combination of survey questionnaires, focused group discussion, and onsite temperature measurements. No quantitative relationship between temperature and work severity was established. Authors suggested that further studies estimating the exact nature of thermal loads experienced by construction workers were essential for the long term benefit of these workers.

From the literature reviewed, the lack of sufficient research into the direct effects of the thermal environment on manual handling tasks is apparent and more studies are required to assess the impact of temperature on physical capability. Hence, it was decided to evaluate the impact of heat and cold stress on human strength.

EXPERIMENTAL DETAILS

Laboratory experimentation on 99 human subjects (volunteers) under varying temperature conditions was done in order to assess the effect of changing the temperature on strength of the subjects. A physically fit subject (pre-cleared by physician) was asked to sit in the controlled environment for about 30 minutes for acclimatization, after which he underwent the strength tests. The subject executed a standard test protocol on a dynamometer during which average value of push strength applied for a period of 30 seconds was obtained. Similarly, the average value of pull strength, pedal strength, and grip strength were obtained using corresponding dynamometers. The temperature was varied and the subject underwent the same standard test protocol at six different temperatures, namely, $5^{o}C$, $10^{o}C$, $20^{o}C$, $25^{o}C$, $30^{o}C$ and $40^{o}C$ (dry bulb temperature). Humidity was not controlled but recorded for every test. The collected data was analyzed to assess and quantify the relationship between environmental conditions and strength. Statistical correlation analysis using Excel was carried out to quantify the effect of ambient conditions on strength.

RESULTS AND DISCUSSION

Studies on the Effect of Ambient Dry Bulb Temperature on Physical Strength

The push, pull, pedal and grip strength of subjects were obtained at different ambient dry bulb temperatures for this study. Due to physical attributes, there was a large variation in maximum strength exerted by individuals. Since the focus of the current research was to study the effect of temperature on human strength it was decided to normalize the strength values. For this, the actual minimum strength recorded of an individual at a given temperature was converted to unity (1.0) and strengths of the same individual at other ambient temperatures were obtained by normalization. The average of normalized push, pull, and pedal and grip strength of all the 99subjects versus temperature is given in Table1. It was observed that peak strength in all cases was at $20^{o}C$ or $25^{o}C$.

Table 1: Temperature Vs. Normalized Average Push, Pull, Pedal and Grip Strength

Temperature	Normalized Average Push Strength	Normalized Average Pull Strength	Normalized Average Pedal Strength	Normalized Average Grip Strength
5	1.1424	1.2237	1.1506	1.1539
10	1.3363	1.4452	1.3588	1.3762
20	1.5872	1.7568	1.5638	1.6000
25	1.6146	1.8047	1.6091	1.5992
30	1.2964	1.3200	1.3328	1.2548
40	1.0656	1.0592	1.1103	1.0394

The statistical analysis gave a second order "inverted-U" relationship between strength which is the dependent variable and temperature the independent variable is obtained (Figure 1 to Figure 4). The smooth line indicates the curve given by the regression equation and the plot indicates curve from the actual data.

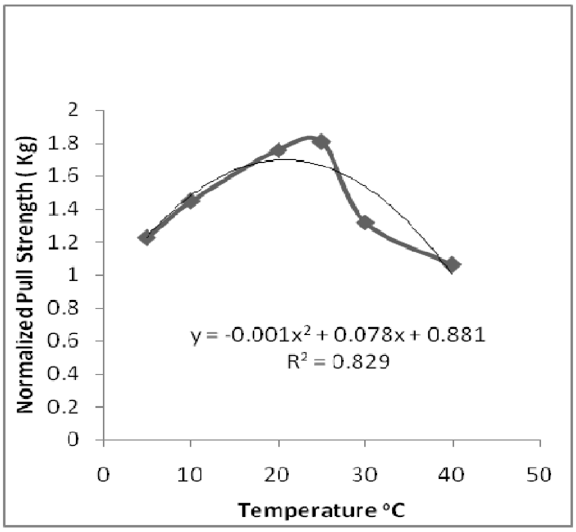

Figure 1: Normalized Average Push Strength vs. Temperature

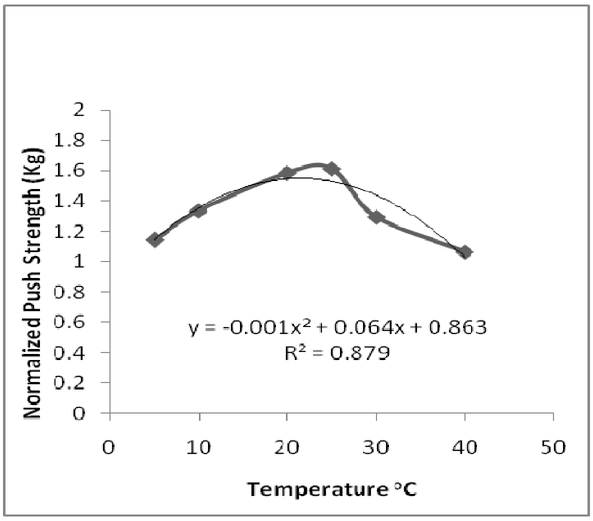

Figure 2: Normalised Average Pull Strength vs Temperature

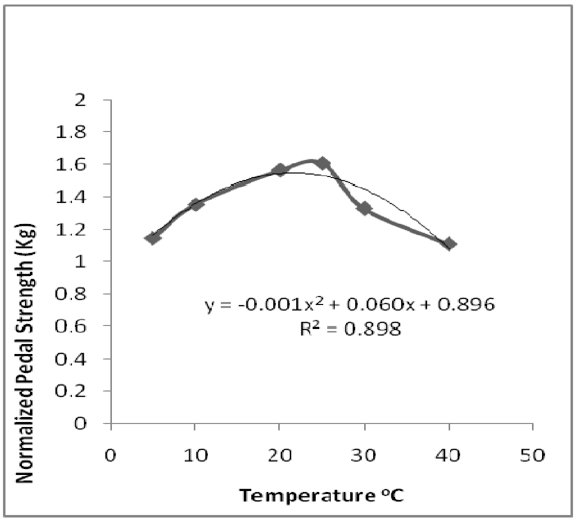

Figure 3: Normalized Average Pedal Strength vs. Temperature

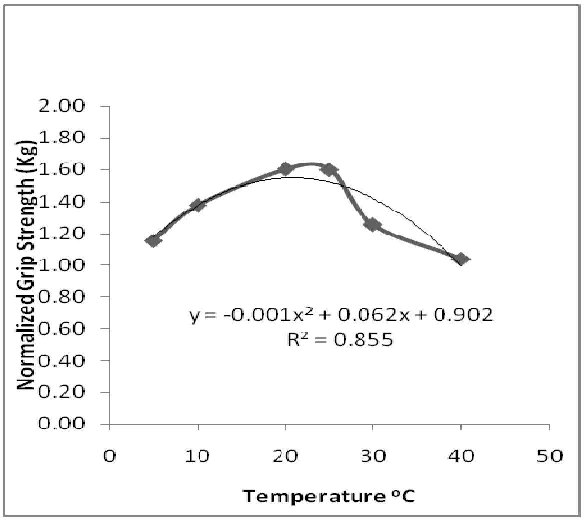

Figure 4: Normalised Average Grip Strength vs.Temperature

Studies on Percentage Drop in Strength

As the relationship between strength and temperature was found to be an "inverted -U", it was decided to find out the percentage drop in strength at the two extreme temperatures. Earlier studies by researchers [8,20] had found a 21.5% decrease in weight lifted and 35% adverse impact on productivity, respectively under the influence of heat stress. To quantify the drop in strength with temperature, the maximum strength of the subject was found and the percentage drop in strength at the two extremes, namely, 5°C and 40°C were calculated. This is shown in Table 2.

Table 2: Percentage Average Drop in Strength at 5°C and 40°C

Strength	% Average Drop in Strength at 5°C	% Average Drop in Strength at 40°C
Push strength	29.66	34.03
Pull strength	32.56	40.91
Pedal strength	28.88	31.07
Grip strength	30.44	37.16
Average of push, pull, pedal, grip	30.38	35.79

An average drop across push, pull, pedal and grip strength of 30.38% was observed at 5°C and of 35.79% at 40°C. It was also observed that out of all the strength measurements the highest drop in strength is observed for pull strength, which may probably be due to the nature of the task being against gravity.

A similar procedure was used to find the percentage drop in strength at all temperatures studied between 5°C and 40°C and is represented graphically in Figures 5 to 8 below.

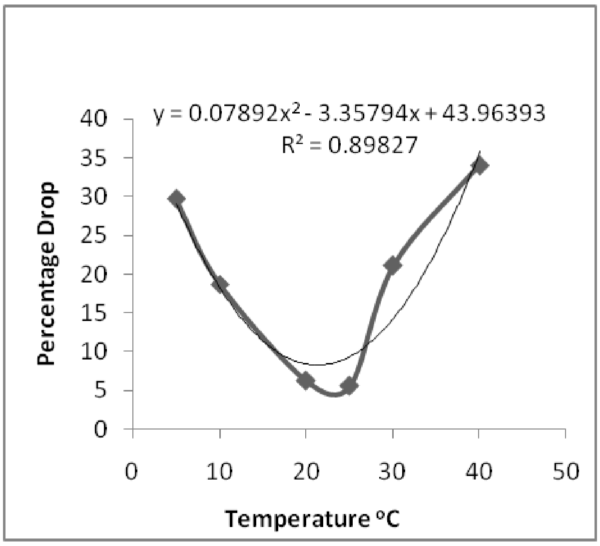

Figure 5: Percentage Drop in Strength - Push Force

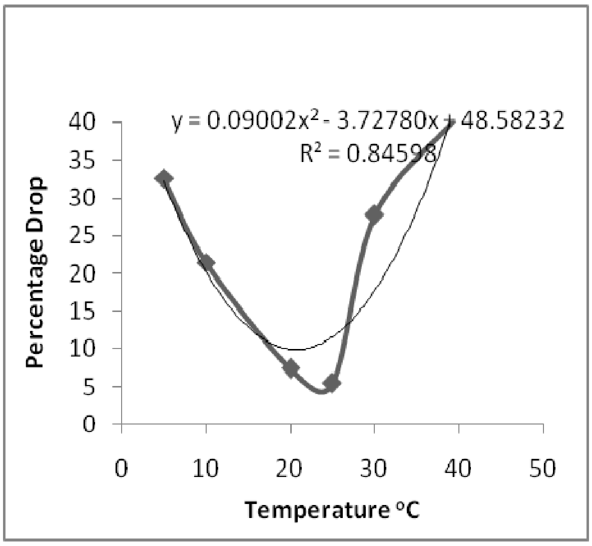

Figure 6: Percentage Drop in Strength - Pull Force

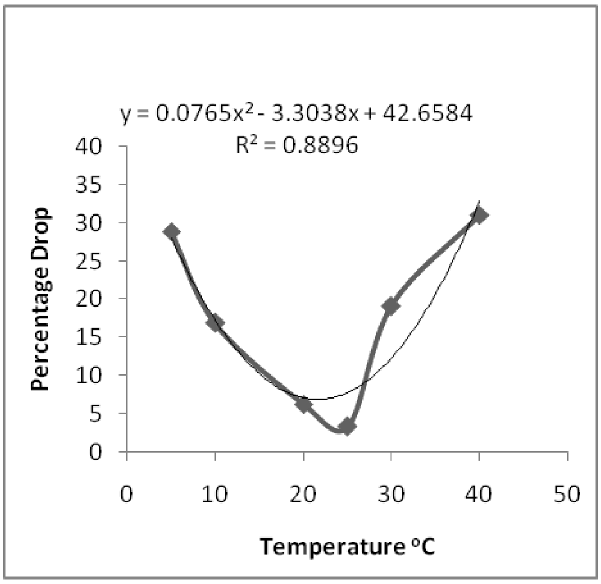

Figure 7: Percentage Drop in Strength Pedal Force

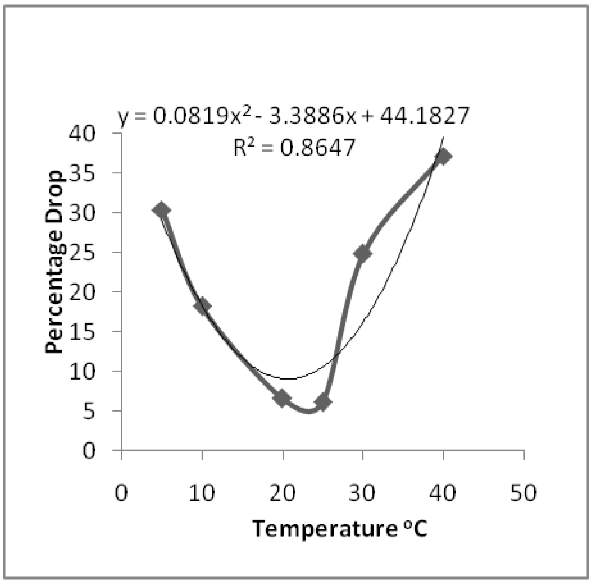

Figure 8: Percentage Drop in Strength Grip Force

Regression analysis of the correlation between percentage drop in strength and ambient temperature was done and is also represented in Figure 5 to Figure 8. The equations obtained in these four graphs may be used to determine percentage drop in strength at any temperature between 5°C and 40°C for push, pull, pedal or grip strength for an individual. Application of these drop in strength values in daily workload allocation may result in reducing worker's health issues.

Studies on the Effect of wet Bulb Globe Temperature (WBGT) on Physical Strength

When the push, pull, pedal and grip strength of subjects was being measured at different ambient dry bulb temperatures, existing humidity values were also recorded. The airspeed in the lab was observed to be 0.5 m/s at all times. From the humidity, dry bulb temperature and airspeed values the corresponding WBGT (indoor) values were obtained using Excel Heat Stress calculator[21]. As humidity was not controlled and existing values of humidity at given dry bulb temperature were used to obtain WBGT, a uniformity in WBGT values for all 99 subjects was not possible to achieve. Therefore the WBGT values were sorted into class intervals and strength values in the interval were averaged. Results are shown in Table 3. It is seen that the maximum push strength and pull strength was observed in the class 15°C to 17°C WBGT, maximum pedal strength in the class 19°C to 21°C WBGT, and maximum grip strength in the class 13°C to 15°C WBGT.

Table 3: WBGT (Indoor) Vs. Normalized Average Push, Pull, Pedal and Grip Strength

WBGT °C	Average of Push Strength Values	Average of Pull Strength Values	Average of Pedal Strength Values	Average of Grip Strength Values
3-5	1.1576	1.2244	1.1390	1.1664
7-9	1.3200	1.4460	1.3704	1.4308
9-11	1.3270	1.4282	1.4148	1.3912
13-15	1.4026	1.6808	1.4742	1.7287
15-17	1.6945	1.7825	1.5657	1.5801
17-19	1.5137	1.7351	1.6152	1.7273
19-21	1.5609	1.6911	1.6683	1.4660
21-23	1.4559	1.4373	1.6029	1.5368
23-25	1.4696	1.6382	1.4577	1.3824
25-27	1.3169	1.2830	1.4496	1.4401

27-29	1.2088	1.2827	1.2301	1.1987
29-31	1.1050	1.1857	1.1416	1.1176
31-33	1.0975	1.1225	1.1689	1.0585
33-35	1.0588	1.0444	1.0891	1.0232
35-37	1.0327	1.0214	1.0726	1.0204
37-39	1.0000	1.0000	1.0063	1.0362

Figure 9 to 12 show the bar chart with a trend line of WBGT classes versus the strength values. In all cases (push, pull, pedal and grip strength) it is observed that there was a substantial drop in strength at extremes (temperature class 3°C to 5°C and 37°C to 39°C WBGT) compared to the peak strength value. To quantify the drop in strength at the two extremes of WBGT classes, the maximum strength exerted by the subject was taken and percentage drop from this value at lowest (3°C to 5°C) and highest (37°C to 39°C) WBGT class intervals were calculated. This is shown in Table 4. It is found that average drop across push, pull, pedal and grip strength of 31.81% was obtained for 3°C to 5°C WBGT class and 41.15% was obtained for 37°C to 39°C WBGT class.

Table 4: Percentage Average Drop in Strength at 3oc to 5oc and 37oc to 39oc WBG

Strength	% Average Drop in Strength at 3°C to 5°C WBGT	% Average Drop in Strength at 37°C to 39°C WBGT
Push strength	31.68	40.98
Pull strength	31.30	43.89
Pedal strength	31.72	39.68
Grip strength	32.52	40.05

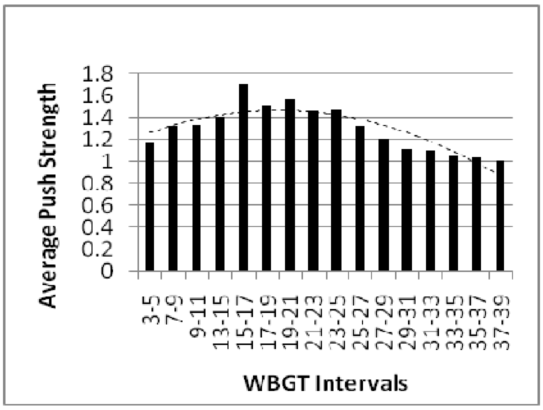

Figure 9: Average Push Strength Vs WBGT

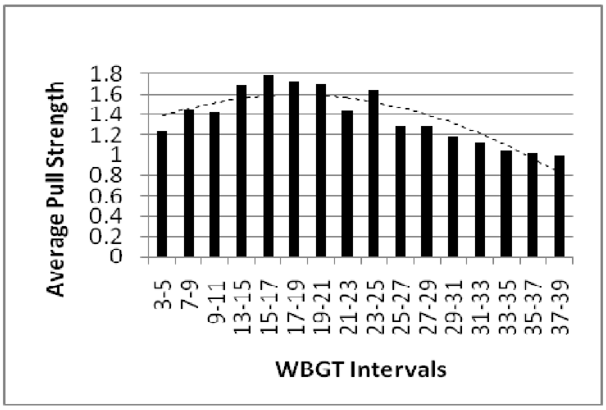

Figure 10: Average Pull Strength Vs WBGT

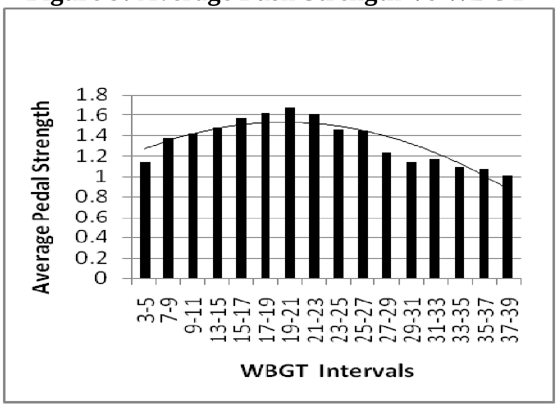

Figure 11: Average Pedal Strength Vs WBGT

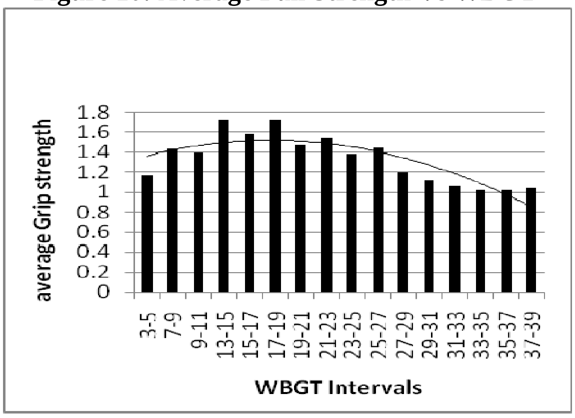

Figure 12: Average Grip Strength Vs WBGT

CONCLUSIONS

In both the dry bulb temperature and WBGT studies it was observed that subjects gave peak performance within comfortable ambient conditions, namely, at dry bulb temperatures of 20°C to 25°C and 13°C to 21°C of WBGT. A decrease in strength was observed at both higher and lower temperatures. The percentage average drop in strength at a low range of temperatures was similar in case of dry bulb and WBGT i.e.,30.38% and 31.81% (Table 2 and Table 4) respectively. However, a much greater percentage drop in the strength of 41.15% was observed at 37°C to 39°C WBGT (Table 4) in comparison to a drop in the strength of 35.79 % at 40°C dry bulb temperature (Table 2). Closer examination of Table 3 shows the lowest strengths among WBGT classes above 33°C. All these classes corresponded to 40°C dry bulb temperature and humidity values of greater than 50%. It can be concluded that the effect of humidity on strength becomes pronounced at temperatures above the 30°C dry bulb and should not be ignored in work content calculations.

In the case of dry bulb temperature studies, a second order "U-shaped" relationship was obtained between the percentage drop in strength and temperature. This equation may be used to predict a drop in strength at any given temperature. However, based on conclusions drawn from the comparison above, while applying this equation above 30°C dry bulb temperature and greater than 50% humidity, an additional drop in strength due to the effect of humidity also needs to be factored into the work content calculations.

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